GEOLOGIC MAP OF THE POLAR REGIONS OF MARS

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DESCRIPTION OF MAP UNITS

The map units are arranged according to their occurrences and associations as outlined in the correlation chart. The origin and composition of many units are obscure or controversial, but their identification is based on objective descriptions of morphologic characteristics visible on Viking images. Many of the units and their type areas occur in equatorial regions (Scott and Tanaka, 1986; Greeley and Guest, 1987); unit symbols, names, and groupings already established there are used here.

NORTH POLAR REGION

Northern plains assemblage

Materials deposited in widespread sheets on northern plains. Boundaries between rock units commonly not well defined, in places indicated by dashed contact.

ARCADIA FORMATION—Smooth, sparsely cratered; lobate fronts visible in places. Embays all neighboring units. (Members 2, 4, and 5 (units Aa_2, Aa_4, and Aa_5) mapped to south, not present in map area.) *Interpretation:* Lava flows and sediments from local sources

Aa_3 Member 3—Forms isolated patches along edge of map area between long 170° and 180°

Aa_1 Member 1—Forms low-lying plains surrounding Alba and Tantalus Fossae

Aps SMOOTH PLAINS MATERIAL—Forms two areas of smooth, sparsely cratered plains north of crater Lyot near edge of map area (long 315° to 340°) and near knobby, undivided material at long 193°. *Interpretation:* Probably of diverse origin, but may primarily consist of eolian deposits

VASTITAS BOREALIS FORMATION—Subpolar plains deposits. Type areas designated in western equatorial region (Scott and Tanaka, 1986)

Hvm Mottled member—Characterized by high-albedo crater deposits superposed on low-albedo, smooth-plains deposits; occurs along more than half of edge of map area; gradational with other members, particularly with knobby member. *Interpretation:* Lava flows, possibly erupted from fissures and small volcanoes, or alluvial or eolian deposits. Mottled appearance due either to relatively fresh, light-colored material exposed during impact-crater excavation or to high-albedo eolian debris trapped within crater ejecta

Hvg Grooved member—Marked by grooves forming polygonal pattern; polygons commonly 5 to 20 km across; small patch at lat 80° N., long 60° in mouth of Chasma Boreale; eroded on south side. *Interpretation:* Degraded lava flows or sediments; grooves may be lava-cooling, periglacial, tectonic, dessication, or compaction phenomena

Hvr Ridged member—Scattered occurrences mostly in western longitudes; gradational with knobby, mottled, and smooth members; in places embayed by Arcadia Formation. Ridges about 1 to 2 km wide and several to tens of kilometers long commonly form polygons 5 to 20 km across; ridge patterns in some southern outcrops are arcuate or concentric, as at lat 56° N., long 173°. *Interpretation:* Degraded lava flows or sediments; ridge pattern may be formed by intrusion of viscous lava in grooves of grooved member or by remnants of dikes on a stripped surface; concentric ridges may result from scarp retreat caused by periglacial or erosional processes

Hvk Knobby member—Characterized by abundant, kilometer-size, dark, knoblike hills spaced generally a few kilometers apart and commonly grouped into linear chains. Occurs in broad circumpolar belt; interknob areas gradational with mottled and ridged members. *Interpretation:* Knobs probably small volcanoes and highly degraded remnants of highland material (unit HNu), crater rims, and older plains material. Interknob plains probably degraded lava flows or sediments

Channel-system and eolian materials

Depositional and erosional units within channels and plains, and dune deposits.

Ach YOUNGER CHANNEL MATERIAL—Smooth, sparsely cratered material within part of channel along edge of map area at long 58°; channel originated from Tempe Fossae region to south (Scott and Tanaka, 1986). Superposed on flood-plain material and mottled and knobby members of Vastitas Borealis Formation. *Interpretation:* Recent fluvial material

Adc CRESCENTIC DUNE MATERIAL—Forms individual and linked crescentic dunes; individual dunes as large as several kilometers across. Occurs along most of edge of Planum Boreum. *Interpretation:* Active barchan dunes made up of sand-size particles consisting of mineral grains or dust and ice aggregates. Occurrence indicates areas of moderate sand accumulation or erosion

Adl LINEAR DUNE MATERIAL—Forms linear, ripplelike patterns of dunes in north polar erg in Arion Planitia and near mouth of Chasma Boreum; wavelength of ripples about 1 to 2 km. *Interpretation:* Forms relatively stable, mature dune field; dune orientations controlled by oscillating wind directions. Presence indicates regime of large sand accumulations in topographic lows

Am MANTLE MATERIAL—Smooth to hummocky deposit, as much as several hundred meters thick; surrounds most of Planum Boreale; extent of unit may vary seasonally. Mapped only north of lat 66° N., where thick enough to obscure features characteristic of members of Vastitas Borealis Formation. *Interpretation:* Eolian deposits derived from seasonal frost and dust accumulation and perhaps erosion of polar layered deposits, polar dunes, and subpolar plains materials

Hchp FLOOD-PLAIN MATERIAL—Smooth, moderately cratered material with longitudinal albedo streaks; occurs at edge of map area at long 60°, adjacent to younger channel material; forms north tip of flood-plain deposits along west edge of Acidalia Planitia; embayed by member 1 of Arcadia Formation. *Interpretation:* Deposits from fluvial channels south of map area (Scott and Tanaka, 1986)

Western volcanic assemblage

ALBA PATERA FORMATION

Hal Lower member—Forms gently sloping plateau that emerges from Vastitas Borealis Marked by degraded lobate flow fronts and small impact craters; displays grabens a few kilometers across and tens to hundreds of kilometers long; embayed by member 1 of Arcadia Formation. To south, unit covers broad region containing most of Alba and Tantalus Fossae; north edge of region extends into map area. Previously mapped as cratered and fractured plains material (Dial, 1984). *Interpretation:* Older, highly degraded lava flows originating from Alba Patera and surrounding fractures

Plateau and high-plains assemblage

Consists of ancient highland terrain and local tracts of younger deposits that stand relatively high.

POLAR DEPOSITS

Api Polar ice deposits—Residual polar cap of high-albedo material imaged in late spring and summer (L_S=92 to 154), 1977; occurs on high surfaces of Planum Boreum, in irregular patches north of lat 70° N. between longs 10° and 270°, and on crater floors. *Interpretation:* Photometry and infrared thermal mapping indicate water-ice and dust composition (Kieffer and others, 1976). Covered by CO_2 frost that extends continuously as far south as lat 65° N. during winter. Some outlier deposits may be wind-streaked material composed mainly of ice or frost

Apl Polar layered deposits—Form Planum Boreum and nearby mesas south of Chasma Boreale; smooth, uncratered; moderate albedo; Planum Boreum cut by troughs in swirl pattern; troughs expose alternating light and dark layers tens of meters thick, some unconformable; total thickness estimated at 4 to 6 km (Dzurisin and Blasius, 1975) or 1 to 2 km (Wu and others, in press). Composite age of deposits uncertain. *Interpretation:* Deposits of mixed ice and dust. Light and dark layering caused by variation in dust-to-ice ratio; reflects long-term climate changes. Unconformities attributed to alternating periods of erosion and deposition that vary from place to place or to glacial surges

Hnu UNDIVIDED MATERIAL—Forms high-standing hills and irregular mesas several to more than 10 km across; largest exposures make up Scandia Colles and rims of large craters nearby. Resembles knobby member of Vastitas Borealis Formation but hills generally larger and more closely spaced. *Interpretation:* Remnants of ancient highland material projecting above plains; heavily eroded by mass wasting

SOUTH POLAR REGION

Channel-system and eolian materials

Am MANTLE MATERIAL—Thin, smooth, sparsely cratered material in pits of Angusti and Sisyphi Cavi. *Interpretation:* Cover of dust deposited by seasonal dust storms and perhaps material eroded from pit walls by mass wasting

Ad DUNES AND DUNE-CAPPED MATERIAL—Thick, circular, steep-edged deposits covered by complex linear dunes and dune chains; dune ridges concentric to edges of deposits. Unit commonly occurs on north sides of crater floors and in low areas near edge of polar layered deposits on Terrae Sirenum and Cimmeria. *Interpretation:* Locations and complex shapes suggest dunes composed of ice and fine material derived from polar layered deposits; underlying deposits may consist of polar layered material; deposited in areas of low wind strength

Hch OLDER CHANNEL MATERIAL—Smooth, longitudinally grooved deposits within two long sinuous channels: one channel winds through Charitum Montes and is overlain by ridged plains material in Argyre Planitia; other channel runs along border of Malea Planum and Promethei Terra. *Interpretation:* Channels cut by flowing water or ground-ice sapping; deposits may include alluvial material, glacial till, or debris flows

Plateau and high-plains assemblage

Dominates map area; consists of rock units having moderate to high relief. Includes rugged, heavily cratered materials, also volcanic and polar deposits forming high plains.

As SLIDE MATERIAL—Lobate, high-albedo, striated, and uncratered slope deposits extending 5 to 10 km from massifs in southern Argyre Planitia. *Interpreta*tion: Aprons of ice and debris eroded from highland terrain; emplaced by gelifluction, creep, or glacial flow

POLAR DEPOSITS

Api Polar ice deposits—Form residual high-albedo feature of Martian southern summer (L_S=348), 1977; offset from axial-pole position about 200 km south at long 45° surface striated. *Interpretation:* Water-ice cap, usually covered by CO_2 because of colder temperature relative to north pole; striations due to relatively strong winds

Apl Polar layered deposits—Smooth, sparsely cratered, moderate-albedo material that forms Planum Australe; in places characterized by alternating light and dark layers tens of meters thick; complete sequence as much as 3 km thick. Cut by curvilinear to irregular scarps and troughs, which include Chasma Australe; underlying terrain at base of troughs unscarred. *Interpretation:* Ice and dust deposits; albedo layering related to ice content that, in turn, depends on climate. Some scarps and troughs carved by prevailing wind patterns; others possibly formed by glacial surge. Lack of etching in underlying terrain indicates relative softness of layered material

PLATEAU SEQUENCE—Forms rough, heavily cratered to smooth, relatively flat terrain throughout region. Subdivision of units based on relative age and type and degree of surface modification

Hpl_3 Smooth unit—On Argyre Planitia and within intercrater areas on plateau-sequence material, forms flat, moderately cratered, smooth plains; embays all adjacent units; flow fronts and wrinkle ridges rare. On Malea Planum, forms irregular surfaces superposed on ridged plains material; eroded into knobs along edges; preserved in broad low areas or below superposed crater ejecta (as at lat 58° S., long 327°). *Interpretation:* Lava flows from local sources or eolian deposits, except perhaps on Malea Planum, where may be remnants of ice-rich mantle material

Npl_2 Subdued cratered unit—Forms moderately rough, uneven plains in broad, low-lying intercrater and intracrater regions; high density of craters 1 to 10 km across; large subdued crater rims common; small wrinkle ridges in places; flow fronts rare. *Interpretation:* Thin mantle of interbedded lava flows and eolian deposits

Npl_1 Cratered unit—Most widespread highland rock unit; high density of craters >10 km in diameter, rugged surface, moderate relief; sparse distribution of channels, fractures, and small ridges. *Interpretation:* Materials formed during period of high impact flux; probably a mixture of lava flows, pyroclastic material, and impact breccia

Npld Dissected unit—Similar in occurrence and appearance to cratered unit, but highly dissected by networks of small channels. *Interpretation:* Origin same as cratered unit; channels produced by rain-water runoff or ground-ice sapping

Nple Etched unit—Similar to cratered unit, but marked by flat-bottomed troughs and knobs several kilometers in size or larger; occurs in patches in Noachis Terra and Malea Planum *Interpretation:* Cratered unit degraded by wind erosion and removal of ground ice, perhaps induced by local volcanic heating

Nplr Ridged unit—Forms rough, moderately to heavily cratered terrain containing wide, long ridges and scarps; most occurrences form wide swath along south edge of Malea Planum and Promethei Terra. *Interpretation:* Probably interbedded volcanic rocks and impact breccia; ridges formed by volcanism or folding and normal faulting, perhaps along preexisting structures related to Hellas impact basin and other ancient crustal structures

Nplh Hilly unit—Hilly facies of cratered unit, but has higher relief due to pronounced crater rims, massifs, and fault scarps; forms rim of Argyre impact basin (Charitum Montes) and other hilly terrain; underlies cratered unit. *Interpretation:* Mostly rim material of Argyre impact basin, probably uplifted crustal material and impact breccia; other occurrences may be volcanic, tectonic, or impact-related mountains

Hr RIDGED PLAINS MATERIAL—Forms broad, planar, moderately cratered surfaces marked by long, linear to sinuous ridges resembling those on lunar maria; ridges commonly several kilometers wide and tens of kilometers long. Covers most of Malea Planum and many intercrater regions, particularly in Terrae Sirenum and Cimmeria; embays all adjacent units except for some young smooth materials. *Interpretation:* Extensive flows of low-viscosity lava erupted at high rates from local sources, including fissures and Amphitrites, and Peneus Paterae

AMPHITRITES FORMATION

Hap Patera member—On Malea Planum forms Amphitrites and Peneus Paterae, which are characterized by circular patterns of both wrinkle ridges and faults. Type area: Amphitrites Patera. *Interpretation:* Material of volcanic centers and associated ring faults from which ridged plains material was extruded

Had Dissected member—Ridged plains material deeply furrowed by sinuous channels and gullies that trend downslope toward Hellas Planitia (centered at lat 45° S., long 290°); many superposed and embayed impact craters. Forms plains of northern Malea Planum; gradational with ridged plains material; embays rim material of Hellas Basin. Type area: northern Malea Planum. *Interpretation:* Relatively soft ridged plains material or mantle modified by channeling

DORSA ARGENTEA FORMATION—Forms polar plains near Angusti and Sisyphi Cavi and Promethei Rupes; embays older highland rocks and ridged plains material; underlies polar layered deposits; middle Hesperian age indicated by crater counts

Hdu Upper member—Deposits generally broad and smooth, lightly pitted in places, except at Dorsa Argentea, where deposits have sinuous, braided, kilometer-wide ridges as long as 150 km. Edges locally distinct and lobate; embays surrounding cratered terrain. Type area: Dorsa Argentea. *Interpretation:* Lava flows originating from unrecognized fissure vents in vicinity of crater Schmidt, Sisyphi Montes, and other local sources; ridges may be unusual lava-flow features or eskers

Hdl Lower member—Similar to upper member but more degraded; forms mostly smooth pitted plains around cavi. Type area: plains surrounding Angusti and Sisyphi Cavi. *Interpretation:* Eolian mantle or lava flows originating from local fractures and possible volcano at Sisyphi Cavi. Highly degraded by cavi formation, perhaps facilitated by removal of underlying ground ice

HELLAS ASSEMBLAGE—Map units associated with impact and fill of Hellas impact basin (Greeley and Guest, 1987). Only one of these units is exposed in south polar map area

Nh_1 Basin-rim unit—Rugged to mountainous, heavily cratered and resurfaced material of Hellas Basin rim east of Malea Planum. *Interpretation:* Impact breccia and interbedded volcanic material of ancient crust; impact structures such as radial troughs not seen, probably degraded and buried by surficial deposits

Nhu UNDIVIDED MATERIAL—Rough, massive deposits exposed in walls and floors of large, irregular pits as much as a kilometer deep at Angusti and Sisyphi Cavi; forms closely spaced, rounded hills a few kilometers across; grades into etched unit of plateau sequence. Most of unit underlies Dorsa Argentea Formation. *Interpretation:* Plateau sequence and basement rocks; pitting and degradation caused by removal of ground ice, mass wasting, and eolian exhumation of poorly consolidated material

CONTACT Dashed where approximately located or gradational; queried where doubtful

FAULT OR GRABEN—Bar and ball on downthrown side of fault

RIDGE—Symbol on ridge crest

SCARP—Line marks top of slope; barb points downslope

NARROW CHANNEL

CALDERA

DOME—Low, moderately sloping; origin and age uncertain

MOUNTAIN—High, rugged; origin and age uncertain

VOLCANO—Queried if origin conjectural; age uncertain

IMPACT CRATER MATERIALS—Yellow if superposed, brown if partly buried. May include rim crest (hachured), central peak, smooth floor (symbol s). Symbol c denotes crater-rim and ejecta materials. Materials of impact craters less than about 100 km across not mapped. Ejecta from crater Lyot, centered at lat 50° N., long 331°, shown by symbol el.

INTRODUCTION

These geologic maps of the north and south polar regions of Mars, extending to 55° north and south latitudes, overlap by 2° the geologic maps of the western and eastern regions, which extend to lat ±57°. The maps were compiled from Viking medium-resolution photomosaics at scales of 1 :2,000,000 and from higher resolution Viking images. The quality and resolution of the Viking pictures are superior to those of Mariner 9 used to prepare the previous map (Scott and Carr, 1978) that includes these two regions. Because of the Viking orbital configuration, a vast number of high-resolution images of the area within 10° of the north pole was obtained, whereas many areas in lower northern latitudes were covered only by low-resolution images. In contrast, the south polar region is nearly completely covered by images at medium resolution but is not imaged at high resolution.

Names of geologic units and a method for relative-age determinations based on crater densities were developed for the geologic map of the western equatorial region (Scott and Tanaka, 1986). These names, where applicable, and this dating method were also used on these polar maps. New geographic nomenclature and several new geologic units were added.

The Mariner 9-based map of the north polar region (Scott and Carr, 1978) indicates mottled, ridged, and cratered plains surrounding the polar deposits. Recent mapping at 1:5,000,000 scale and crater counts above lat 65° N. by Dial (1984), based largely on Viking images, have outlined the vast sand seas that surround the north polar ice cap, changed the age of the plains of Vastitas Borealis from Noachian-Amazonian to Amazonian-Hesperian, identified faulted terrain associated with Alba Patera, and reclassified as impact craters three structures previously identified as volcanoes. Dial subdivided the plains units largely on the basis of albedo, mantling by debris, and presence of fractures, but only Mariner 9 frames were available to him for much of the plains. Our mapping covered 10° more of latitude and used new Viking-based 1:2,000,000-scale photomosaics (resolution ranges from 150 to 400 m/pixel) that fully cover these plains, as well as high-resolution images of the polar ice cap. We subdivided the northern plains materials, excluding relatively thin eolian deposits, into six members of the Vastitas Borealis and Arcadia Formations (Scott and Tanaka, 1986).

Our south polar map was based on Viking 1:2,000,000-scale photomosaics made up mostly of images ranging in resolution from about 130 to 200 m/pixel. Highest resolution images are about 110 m/pixel. Some areas, particularly those within the arc between lat 55° and 60° S. and long 0° and 180°, are covered only by lower resolution images (200 to 400 m/pixel). Previous mapping at 1:5,000,000 scale south of lat 65° S. (Condit and Soderblom, 1978), based on Mariner 9 images (300 to 3,000 m/pixel), identified the extent of the polar deposits, the rugged character of the highlands, and large areas of relatively smooth plains. Important modifications in the new south polar map include the following: (1) a finer subdivision of highland units but without major changes in their relative-age assignments; (2) an extension of the area covered by ridged plains material from a relatively small area to many areas surrounding the south pole; and (3) the inclusion of the Hesperian Dorsa Argentea and Amphitrites Formations, consisting of four units.

The north and south polar regions are strikingly different in physiography, geology, relative age, and surface processes. Most of the differences reflect the contrast between younger lowland plains of the northern hemisphere and older highland terrains of the southern. The northern plains consist of comparatively few rock types that are mostly of Hesperian and Amazonian age. After their emplacement, chiefly as lava flows and sediments, the plains-forming units were extensively mantled and stripped (Carr and Schaber, 1977). These older units now exist only as numerous small knobby hills and pedestal craters throughout the region. Some scattered clusters of larger hills that form Scandia Colles, for example, may be remnants of an old highland surface that projected above the later lava flows of the plains. The plains north of about lat 65° N. are mostly covered by dune fields, dust mantles, and polar layered deposits that form Planum Boreum and some outlying mesas. The extensive residual water-ice cap around the north pole covers most of the layered deposits. In contrast, the rock units of the south polar region are continuations of many highland units of Noachian and Hesperian age that are exposed throughout the equatorial zone. These rocks are overlain south of about lat 70° S. by Planum Australe, a broad, smooth structure composed of layered deposits and a small residual ice cap. Relatively little dune and mantle material surrounds these deposits. The contrasting characters of the polar highlands and lowlands are probably manifestations of different crustal thicknesses of highland and lowland terrain (Bills and Ferrari, 1978) and, therefore, of early global crustal evolution.

Isolated volcanoes, mountains, and domes are scattered throughout the map areas, but as a group they are not assigned a position in the stratigraphic column because the small size of the features precludes reliable crater counts on an individual basis. The stratigraphic relation between low domes (symbol d) and surrounding plains in the north polar region is uncertain. Some mountains in the south polar region are younger and some older than surrounding units. Mountains having features interpreted to be volcanic, such as summit depressions and flow patterns on their flanks and around their bases, are shown in red and are designated by the symbol v. Others may be degraded volcanoes, tectonic mountains, and remnants of plateau sequence materials; these are shown in gray and are designated by the symbol m.

NORTH POLAR REGION

Physiographic setting

The north polar region of Mars consists largely of broad, flat plains surrounding Planum Boreum, a subcircular plateau 1,100 to 1,200 km in diameter centered near lat 87° N., long 0°. The height of the plateau is uncertain; low-resolution stereoimaging of Mariner 9 pictures suggests about 4 to 6 km of relief (Dzurisin and Blasius, 1975), and similar work on Viking images suggests about 1 to 2 km of relief (Wu and others, in press). The plateau is dissected by long, arcuate troughs that form a counterclockwise swirl pattern extending outward from the pole. Depths of these troughs range from 200 to 800 m (Blasius and others, 1982). Outlying remnants of the plateau form an annular belt of mesas partly encircling it between lat 75° to 80° N. and long 100° to 270°. Near the mouth of Chasma Boreale, these mesas are several hundred kilometers from the plateau. Lower latitude areas of the north polar plains are interrupted by knob-shaped highland remnants that make up Scandia Colles and by scattered impact craters as large as 140 km in diameter. A belt of linear dunes forms the broad, arcuate Olympia Planitia adjacent to Planum Boreum between long 120° and 240°

Stratigraphy and structure

The oldest rocks in the map area are *undivided material* (unit HNu). Its most widespread outcrops form the knobby hills of Scandia Colles, which are interpreted to be remnants of ancient cratered terrain (Morris and Howard, 1981). Although their surfaces are too degraded for meaningful crater-density determinations, the hills are considered Noachian-Hesperian in age because they include a crater 150 km in diameter that resembles craters of Noachian age in the cratered terrain of the equatorial and south polar regions, and because the hills are embayed by upper Hesperian plains material. They are likely to be similar in composition to the plateau sequence (highland rocks), which probably consists of interbedded impact breccia and lava flows, in the equatorial and south polar regions. Erosion of the early heavily cratered terrain materials probably occurred during late Noachian time and continued during Hesperian time, as evidenced by stripping of upper Hesperian plains materials that had embayed the older highland remnants.

Early in the Hesperian Period, lavas of the *lower member* (unit Hal) of the *Alba Patera Formation* flowed northward beyond lat 60° N., where they were moderately fractured by the late Hesperian, northeast-trending faults of Alba and Tantalus Fossae. Also during the late Hesperian, the north tip of an extensive deposit of *flood-plain material* (unit Hchp) was emplaced along the west edge of Acidalia Planitia (Scott and Tanaka, 1986).

Much of the north polar plains is covered by materials of the Vastitas Borealis Formation. Cumulative densities of craters larger than 5 km in diameter indicate that the formation is middle to late Hesperian in age, which agrees with counts by Dial (1984). The formation is divided into four members on the basis of the generally mutually exclusive dominance of knobs, grooves, ridges, and mottling, although at many places the members are gradational. The small, kilometer-size hills that characterize the *knobby member* (unit Hvk) were interpreted as small volcanoes or highly degraded remnants of highland material (Frey and others, 1979; Scott, 1979). Interknob surfaces are commonly grooved, ridged, mottled, or mantled. This unit was mapped as both mottled and mantled cratered plains material in the north polar area (Dial, 1984) and as hummocky mottled plains material and knobby plains material in the northern part of the Mare Acidalium quadrangle (Witbeck and Underwood, 1984) . The *grooved member* (unit Hvg) is characterized by a pattern of grooves that form polygons generally 5 to 20 km across; the member is clearly exposed at the mouth of Chasma Boreale but may be covered by mantle material elsewhere. Dial (1984) assigned a lower Amazonian age to this exposure. The origin of the grooves has been attributed to ice wedging, ground-ice decay, thermal contraction of lava flows, dessication, tectonism, or compaction (Carr and Schaber, 1977; Scott, 1979; Helfenstein and Mouginis-Mark, 1980; Pechmann, 1980; McGill, 1985). The *ridged member* (unit Hvr) consists of ridges 1 to 2 km wide forming two distinct pattern types: (l) arcuate, locally concentric patterns possibly formed by retreat of a debris and ice mantle (Carr and Schaber, 1977) or by subsurface ice removal from plains material (Guest and others, 1977); and (2) polygonal patterns that appear similar in size and shape to those of the grooved member; the ridges locally grade into grooves. Pechmann (1980) proposed that the ridges are either the result of high-viscosity lavas extruded through the grooves or the remnants of resistant materials, emplaced in former grooves, which now protrude after stripping of interridge areas. Alternatively, the ridges may be subglacial volcanic deposits (moberg ridges). The *mottled member* (unit Hvm) consists of bright splotches of impact-crater ejecta superposed on both smooth and patterned dark plains material. The contrast in albedo may be caused by eolian material trapped on rougher crater surfaces or by light-colored subsurface material excavated by impact craters (Soderblom and others, 1973b; Carr, 1981). This unit makes up most of the area between lat 55° to 60° N. and long 175° to 60°. Formerly, the mottled member was mapped more extensively in the north polar plains and was not distinguished from other members of the formation (Soderblom and others, 1973b; Dial, 1984). The members of the Vastitas Borealis Formation are overlain by layered and mantle material near the pole, but where they can be identified beneath the mantle, they are shown by symbol in parentheses. Some low domes as large as 50 km in diameter that protrude through the mantle material near lat 75° N., long 155° may be viscous lava flows or volcanoes that were source vents for some of the surrounding plains materials. The general composition of the Vastitas Borealis Formation is uncertain; possible origins include lava flows and alluvial and eolian sediments (Carr and Schaber, 1977; McGill, 1985).

Early in the Amazonian Period, plains material of *member 1* (unit Aa_1) of the Arcadia Formation flooded and embayed the northern periphery of the Alba Patera lava flows and members of the Vastitas Borealis Formation. *Smooth plains material* (unit Aps) was deposited as well, principally north of crater Lyot. In the middle Amazonian, small patches of *member 3* (unit Aa3) *of the Arcadia Formation* were emplaced at lat 55° N. between long 170° and 180°. North of Tempe Fossae, *younger channel material* (unit Ach) was deposited on older floodplain material and members of the Vastitas Borealis Formation.

The *polar layered deposits* (unit Ap1) also overlie the Vastitas Borealis Formation. These deposits have been described extensively by other workers, including Blasius and others (1982) and Howard and others (1982). They make up Planum Boreum and are exposed within troughs that form its swirl pattern. The deposits consist of a series of alternating light and dark layers, each a few tens of meters thick, that are continuous for hundreds of kilometers. Thinner beds may be present but are not resolvable in available images. The deposits probably consist of water ice and dust (Kieffer and others, 1976), which probably is transported poleward by wind storms and is contained in CO_2-ice particles deposited on the poles during winter (Cutts, 1973). Dust accumulation at present on the north polar layered terrain is estimated to be about $4x10^{-2}$ cm/yr (Pollack and others, 1979). The alternation of layers may reflect changes in the ice-to-dust ratio, which are possibly a result of climatic oscillations caused by rotational and orbital perturbations having characteristic periods of 51,000 to 2,000,000 years (Cutts and others, 1979; Carr, 1982). Eroded outliers of layered materials, and possibly the unconformities in the layered sequences (Cutts and others, 1976), indicate past, and possibly continuing, erosion of parts of the deposits by eolian and insolation processes. The paucity of impact craters on the layered deposits suggests surface ages of no more than a few tens of million years (Carr, 1982), but the age of the deposits themselves is uncertain because they may be periodically reworked by rotational migration of the large chasmata and troughs (Howard, 1978; Cutts and others, 1979). Alternatively, these large spiral valleys and the unconformities in the valley walls may have resulted from glacial surges partly directed by Coriolis forces (Weijermars, 1986).

The residual *polar ice deposits* (unit Api) of late Martian spring and summer were mapped from medium-resolution photomosaics. The residual ice cap occurs mainly on the plateau surface of the polar layered deposits and in low areas (such as crater floors) north of about lat 70° N. Although it is overlain by a winter cap of solid CO_2, Viking thermal and reflectance data show that the residual north polar cap is composed of water ice and dust (Kieffer and others, 1976). Even the smaller ice patches are relatively stable on the short term because only small amounts of water ice sublime during the summer; however, long-term climatic variations would alter their distribution pattern. The center of the cap is displaced nearly 200 km to the south of the axial-pole position at long 0°, away from extensive linear dune and mantle deposits; this displacement may be a result of prevailing wind patterns.

Extensive dune deposits surround the north pole. They are probably composed of sand-size mineral grains and bonded aggregates (Sagan and others, 1977; Greeley and others, 1982). Dune patterns (Breed and others, 1979) and volumetric considerations (Thomas, 1982) suggest that these particles are eroded from the polar layered deposits. Both the layered deposits and the dune sand may have been derived from fluvial deposits (McCauley and others, 1980) or other erosional debris (Tsoar and others, 1979) from the middle and upper northern latitudes. Patches of *crescentic dune material* (unit Adc) surround most of the pole between lat 75° and 80° N. *Linear dune material* (unit Adl), which forms a finely rippled topography seen on high-resolution images, occurs mostly adjacent to polar layered deposits in Olympia Planitia and near the mouth of Chasma Boreale. The linear dunes indicate a large sand supply deposited in a topographic basin over a long period of time, whereas the crescentic dunes form where sand supply is smaller and more transient (Breed and others, 1979).

Surrounding the pole, *mantle material* (unit Am) consists of surficial deposits generally less than 200 m (Squyres, 1979) or 600 m (Botts, 1980) thick that subdue and bury topographic and albedo features on the underlying plains materials. The mantle was initially identified as burial and infilling material of impact craters and was interpreted to consist of eolian dust (Soderblom and others, 1973a), perhaps deposited similarly to the polar layered deposits but on an ice-free surface (Squyres, 1979). The mantle covers large areas as far south as lat 30° N. (Soderblom and others, 1973a, 1973b; Dial, 1984).

SOUTH POLAR REGION

Physiographic setting

The south polar region of Mars consists largely of highland terrain rising several kilometers above the Martian datum. Elevations were obtained from Mariner 9 radio occultation and ultraviolet spectrometer data (Dzurisin and Blasius, 1975) and Viking photogrammetrically derived topographic maps (Wu and others, in press). The south pole is capped by a plateau of polar layered deposits, Planum Australe, whose relief is generally 2 to 3 km but more than 5 km where it is covered by polar ice deposits. Planum Australe is oblong in plan, about 1,600 km long and 1,200 km wide, and is offset about 300 km from the geographic pole along the prime meridian. The surface of this plateau slopes downward into an 850-km-diameter impact basin whose rim is partly outlined by Promethei Rupes (Wilhelms, 1973). Along the edge of the map area lie rugged terrains of the Argyre and Hellas impact-basin rims. Many impact craters exceeding 100 km in diameter occur in the highland terrain surrounding Planum Australe. The south polar region also includes two areas of steep-sided depressions several hundred kilometers across, Angusti and Sisyphi Cavi, which contain pits more than 1 km deep.

Stratigraphy and structure

One of the two oldest materials exposed in the south polar region is the *basin-rim unit* (unit Nh_1) of the *Hellas assemblage* (Greeley and Guest, 1987), which forms the rim of the Hellas impact basin. This unit is rugged and heavily cratered, probably composed of impact ejecta and faulted crustal material (Potter, 1976; De Hon, 1977; Peterson, 1977). On the southeast side of Hellas Planitia, the basin-rim unit extends as far as 1,800 km from the basin rim, but, on the west side, it extends for only 200 to 300 km (Peterson, 1977). Possibly this asymmetry is due to ejecta from some smaller impact craters on the east side of Hellas Planitia (Potter, 1976), extensive resurfacing of the western rim area, or the obliquity of the Hellas impact that may have preferentially distributed ejecta to the southeast.

In contrast, the other early Noachian material, the *hilly unit* (unit Nplh) of the plateau sequence, is more uniformly distributed (Scott and Carr, 1978). It is rugged and locally faulted; in addition to making up the rim of the Argyre impact basin, it forms isolated mountains of possible volcanic or tectonic origin. The hilly unit is embayed by the *cratered unit* (unit Npl_1) of the plateau sequence. This unit forms most of the basal rocks throughout the map area. It was produced during the early period of heavy bombardment and is interpreted to consist of interbedded impact breccia and lava flows. In some areas, the cratered unit was extensively dissected by subparallel sets of small narrow channels; these areas are mapped as the *dissected unit* (unit Npld). The channels resemble those produced by terrestrial streams and have been attributed to runoff of rain water (Masursky and others, 1977) or ground-water seepage (Pieri. 1980, p. 148) during a period when atmospheric conditions may have allowed liquid water at the surface. The *etched unit* (unit Nple) consists of etched and knobby components of the cratered unit. Its surfaces were probably formed by sublimation of ground ice, perhaps instigated by local volcanic heating, and deflation of the material.

During middle to late Noachian time, systems of large linear ridges formed on the cratered unit. They are similar to lunar mare and Martian wrinkle ridges in shape and possibly in origin, but generally are larger and occur on older, more rugged surfaces. Material containing the ridges is mapped as the *ridged unit* (unit Nplr) of the plateau sequence. It mostly lies within a swath several hundred kilometers wide that extends across the map area between long 190° and 340° and includes the scarps and ridges that make up Chalcoporos Rupes, Pityusa Rupes, Dorsa Brevia, and Thyles Rupes. Most of these ridges are parallel with the swath. West of long 270°, they appear to be part of a concentric band around Hellas Planitia that includes scarps and troughs 2,000 to 3,000 km west of the center of the low plain (Peterson, 1977). The ridges may be part of a ring system or a result of rejuvenation of older basin structures; possibly they include volcanic material erupted contemporaneously with the structural deformation. East of long 270°, the ridges deviate from their patterns concentric to Hellas and follow trends parallel to local northeast-trending wrinkle ridges. Orientation of the unit's ridges may be controlled by an ancient lineament system defined by the Elysium-Amphitrites and the Tharsis Montes volcanic loci, by deformation produced by an oblique impact at the Hellas basin, or both.

During the later part of the Noachian Period, many intercrater and intracrater areas were covered by a thin mantle of probable volcanic and eolian origin, which embayed but did not completely bury most craters larger than tens of kilometers in diameter. The mantle is mapped as the *subdued cratered unit* (unit Npl_2). At places in the unit are lava-flow scarps and small ridges and channels.

The *smooth unit* (unit Hpl_3) of the plateau sequence has two facies. One form is at Argyre Planitia and within intercrater areas on plateau-sequence material, where it is fairly smooth and moderately cratered. Stratigraphic relations for these outcrops generally indicate a lower to middle Hesperian age. The second form is superposed on ridged plains material in low areas, beneath the ejecta of larger craters, and has steep, irregular, and locally knobby edges indicating extensive erosion. The favored preservation of the unit beneath crater ejecta probably is due to armoring, as proposed for the pedestals of craters in the north polar plains (McCauley, 1973). Although designated Hesperian in age and at least moderately cratered, these outcrops of the smooth unit are not well constrained stratigraphically, and some may be Amazonian in age. Possibly they represent remnants of mantle material similar to the thick, extensive blanket around the north pole.

Other resurfacing of intercrater areas and the southern rim of Hellas impact basin took place during early Hesperian time, forming principally the *ridged plains material* (unit Hr). This unit is characterized by wrinkle ridges generally a few kilometers wide and tens of kilometers long. They have been interpreted as lava flows (Greeley and Spudis, 1981) erupted from buried fissures and large calderas. On Malea Planum, ridged plains material appears to have been erupted from Amphitrites and Peneus Paterae. The ridged plains material within them constitutes the *patera member* (unit Hap) *of the Amphitrites Formation*. The paterae are interpreted to be circular volcanic centers characterized by concentric and radial wrinkle ridges and, at Amphitrites and Peneus Paterae, by ring faults. North of these ring-faulted paterae the ridged plains material is deeply dissected and furrowed (Potter, 1976), and it is mapped as the *dissected member* (unit Had) of the Amphitrites Formation. This unit forms a broad shield and may consist of pyroclastic material or relatively erodable lava flows similar to material on the flanks of Tyrrhena and Hadriaca Paterae northeast of the Hellas impact basin (Greeley and Spudis, 1981).

Two distinctive sequences of smooth, pitted plains material having flow fronts and braided ridges characterize the *Dorsa Argentea Formation*. The flow fronts were not apparent on Mariner 9 images, and the material was interpreted as eolian dust and ice (Condit and Soderblom, 1978). Flow fronts are recognizable south of Promethei Rupes, surrounding Sisyphi Montes, and in Aonia Terra, northeast of crater Schmidt. The material in other areas is pitted but otherwise featureless, and it may be better described as a massive blanket. The two sequences are mapped as upper and lower units on the basis of stratigraphic position and degree of degradation. Most of the *lower member* (unit Hdl) of the Dorsa Argentea Formation occurs within and around Angusti and Sisyphi Cavi; it appears to have been erupted from local fissures, now buried, and from an apparent volcano with a summit crater. The *upper member* (unit Hdu) is more widespread to the east and south, filling low intercrater areas and part of the basin bounded by Promethei Rupes. Its flows also may have issued from buried fissures and possible dome-shaped volcanoes (mapped as mountains). Although generally smoother than the lower member, the upper member has many sinuous, braided ridges of uncertain origin that follow the flow direction of the lavas. Deposits bearing similar ridges in southern Argyre Planitia have been mapped as ridged plains material. Howard (1981) suggested that the ridges may be eskers;

however, supporting stratigraphic relations within the cavi terrain and geologic evidence (for example, fan deposits and glacial features) are lacking. Alternatively, the ridges may be a type of lava-flow feature formed under unusual conditions.

The Dorsa Argentea Formation is deeply pitted and etched at Angusti and Sisyphi Cavi, exposing generally older *undivided material* (unit HNu). This material is composed of plateausequence and other old materials (which are divided according to surface characteristics).

Much of the highland surface adjacent to or surrounded by the upper member of the Dorsa Argentea Formation in the Sisyphi Cavi and Montes region is pitted or knobby (mapped as units HNu and Nple). Originally, Cutts (1973) and Sharp (1973) proposed that wind erosion of ice-rich material caused the pitting, because the adjacent polar layered deposits are etched by the wind. Condit and Soderblom (1978) suggested that the pits were formed by eolian erosion of soft materials that bury the cratered terrain. However, Viking images reveal that the pits are deep (about 1 km) and were excavated through the Dorsa Argentea Formation into the underlying rocks. Howard (1981) suggested that basal melting of ground ice could have formed the cavi, an interpretation consistent with a geologic history in which volcanic activity associated with the lower member of the Dorsa Argentea caused ground-ice melting; such melting could have aided formation of the deeply pitted terrain generally south of lat 75° S. and the etched and knobby terrain to the north. After emplacement of the upper member, minor pitting and degradation continued, particularly in areas already pitted. Channels cutting Charitum Montes and the east edge of Malea Planum deposited *older channel material* (unit Hch), probably also in Hesperian time.

During the Amazonian Period, volcanism and tectonism decreased, and surficial eolian deposits and debris aprons were formed. The *polar layered deposits* (unitApl) are estimated to be either 1 to 2 km thick (Dzurisin and Blasius, 1974) or 2 to 3 km thick (based on maps by Wu and others, in press). They probably consist of interlayered eolian dust and ice (Sharp, 1973). The margins of the deposits, particularly between long 140° and 270°, are relatively thin, and crater rims of the underlying terrain are exposed. The south polar layered deposits are similar in form to their counterparts in the north polar region. In addition, they show long, gently curving scarps etched into the margins of Chasma Australe and other troughs (Cutts, 1973; Thomas, 1982). These scarps, along with the present global dust-storm patterns and the scarcity of surrounding mantle deposits, suggest that the south polar layered deposits are presently being eroded and transported to the north polar region (Scott and Tanaka, 1985). The etched scarps are parallel to the 60° to 90° meridians and appear superposed on a possibly clockwise, spiral pattern of subdued troughs, cutting the troughs at oblique angles. The clockwise spiral pattern indicates the troughs were produced by glacial surge, not by polar winds, on the basis of directional patterns predicted from guidance by the Coriolis effect for each of the processes (Weijermars, 1986). Although the history of the south polar layered deposits is generally uncertain, the fact that a few craters are superposed on them indicates that their surfaces, on average, are older than surfaces of the north polar deposits. The extent of the residual *polar ice deposits* (unit Api), mapped during the Martian southern summer of 1977, is slightly greater than that observed by Mariner 9, perhaps because of retarded ice-cap retreat due to a global dust storm (James and others, 1979). Unlike the north polar cap, the residual south polar ice cap is usually covered by CO_2 year round, but it may occasionally expose water ice during years of high retreat (Jakosky and Barker, 1984).

Relatively recent eolian sedimentation has produced dunes and *dune-capped material* (unit Ad). Dunes cover thick deposits on low plains and within craters outside the periphery of the polar layered deposits; the thick deposits may themselves be remnants of the layered deposits. Mass wasting and dust deposition are evidenced by *mantle material* (unit Am) that fills some pits in Angusti and Sisyphi Cavi and by *slide material* (unit As) surrounding massifs in southern Argyre Planitia. The slides may be aprons composed of eroded debris and ice that flow by gelifluction and frost creep (Carr and Schaber, 1977) or ice creep (Squyres, 1978).

THE MARTIAN POLAR DICHOTOMY

The lowlands and highlands of the north and south polar regions of Mars contrast in physiography, geology, and geophysics. The average elevation of the north polar plains is generally at or below the Martian datum, whereas the south polar highlands surface is about 2 to 4 km above datum (Wu and others, in press). The highland-lowland transition zone is typified by a scarp hundreds of meters to more than a kilometer high; elsewhere it is commonly composed of isolated mesas and knoblike remnants of the highlands extending northward into the plains. Surfaces south of the scarp (including those of the south polar region) are dominated by rugged, heavily cratered terrain. To the north, the surface is relatively smooth except for local patches of knobby remnants of heavily cratered terrain (for example, Scandia Colles). Ancient terrain in the northern lowlands was mostly buried by lava flows or sediments (Scott and Carr, 1978; McGill, 1985), some of which originated in the highlands (Scott and Tanaka, 1986). Geophysical models for the isostatic state of Martian topography suggest that the northern plains low is partly to entirely compensated (Phillips and Saunders, 1975) and underlain by a relatively thin crust (Bills and Ferrari, 1978).

The origin of the northern plains topographic low is uncertain. Suggestions include (1) crustal disruption caused by an increase in mantle volume due to a phase change (Mutch and Saunders, 1976), (2) crustal collapse produced by mantle convection and upwelling due to core segregation (Wise and others, 1979), and (3) massive excavation caused by a giant impact event (Wilhelms and Squyres, 1984) or many large impacts (Frey and others, 1986). Each of these explanations can account for the depth and roughly circular outline of the northern lowlands. The rocks of the northern lowlands are relatively young and obscure possible underlying structures. The highland-lowland transition zone apparently has eroded back hundreds of kilometers, and no broad structural pattern in the highlands relative to the lowlands has been demonstrated. Although gravity models from Viking spacecraft-tracking data may yield some further insights into the highland-lowland boundary problem, those data are relatively poor because spacecraft altitude was high and tracking geometry in the high latitudes was indirect. Thus, the origin of the northern lowlands will remain undetermined until future missions to Mars supply us with new data.

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NOTES ON BASE

This map sheet is one of a series covering the entire surface of Mars at a scale of 1:15,000,000. Sources for the map base were 1:5,000,000-scale shaded relief maps described by Batson and others (1979). Data used in the map portrayal were obtained from Viking Orbiter images.

ADOPTED FIGURE

The figure of Mars used for computing the map projections is an oblate spheroid (flattening of 1/192) with an equatorial radius of 3,393.4 km and a polar radius of 3,375.7 km.

PROJECTIONS

The Mercator projection is used between the 57° parallels; the Polar Stereographic projection is used for the polar regions north and south of the 55° parallels. Scales are 1:15,000,000 at the equator and 1:9,203,425 at the poles. The projections have a common scale of 1:8,418,000 at lat ±56°. Longitude increases to the west in accordance with astronomical convention for Mars. Latitudes are areographic.

CONTROL

Planimetric control for the 1:5,000,000-scale maps used to compile the bases for these sheets was derived from photogrammetric triangulations by use of Mariner 9 pictures (Davies, 1973). This control net was upgraded through the use of Viking data (Davies and others, 1978). At least 85 percent of the image control points lie within 0.5 mm of the positions published in 1978.

MAPPING TECHNIQUE

The mapping bases for this series were assembled from 1:5,000,000-scale shaded relief maps reduced and digitally transformed where necessary to fit the projections. During shaded relief portrayal, features on these bases were used to position details taken from Viking Orbiter pictures. Features were drawn as if illuminated uniformly from the west, through use of airbrush techniques described by Inge (1972) and photointerpretive methods described by Inge and Bridges (1976). The shading is not generalized and accurately represents the character of surface features.

Shaded relief analysis and portrayal were made by Barbara J. Hall (south pole) and Jay L. Inge (north pole).

NOMENCLATURE

All names on this sheet are approved by the International Astronomical Union (IAU, 1974, 1977, 1980, 1983, and 1986). Named features and their positions are taken from published maps of Mars that have scales of 1:2,000,000, 1:5,000,000 and 1:25,000,000.

M 15M±90/0	G Abbreviation for Mars; 1:15,000,000 series; center of maps, lat 90° N. or lat 90° S., long 0°; geologic map (G).

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